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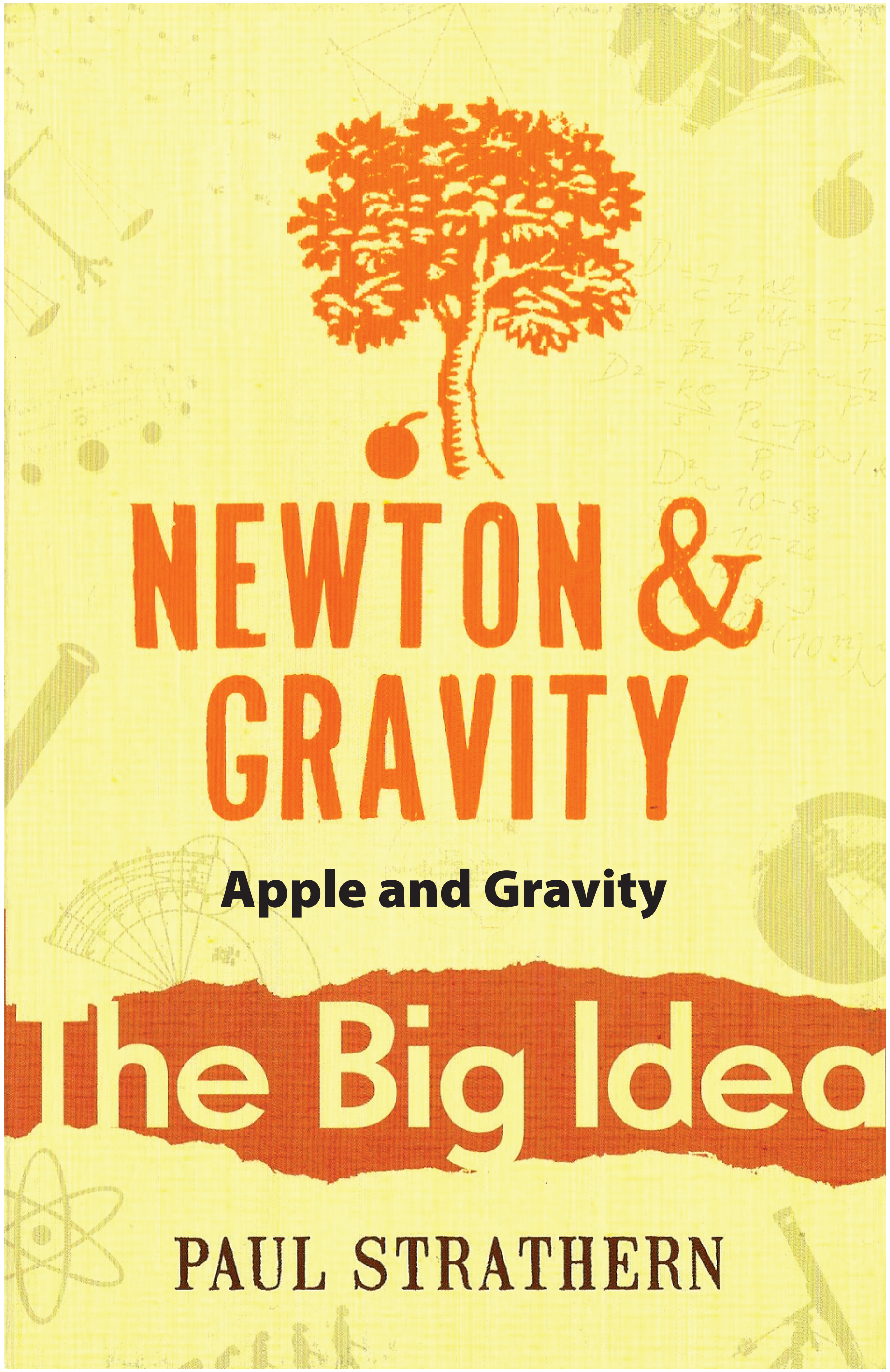

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Excerpts from:

Newton & Gravity (Pages 38-47)

by Paul Strathern

General Note: Paul Strathern is a British author. There are some grammatical and spelling differences between "British" English and "American" English. I did make an effort to "Americanize" the spelling. There are many challenging vocabulary words in these excerpts. These words are underlined. As part of your KWL assignment, look-up all of the words. The words are summarized in the back of this packet. Submit the back page with your KWL.

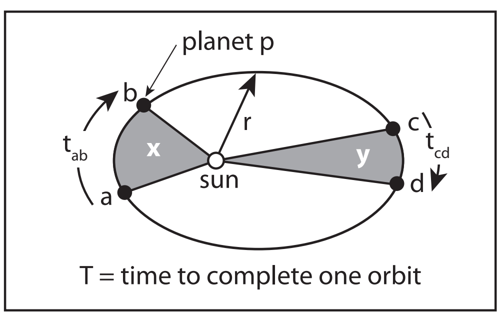
At this stage, Newton's **calculus** still remained in **embryo** form. But even so, he now had the technique which enabled him to undertake his major work. Newton's **transcendent** achievement during the course of 1665-66 was of course concerning gravity.

Newton was later asked how he had achieved this and his other **epoch**-making discoveries. 'By always thinking unto them,' he replied. 'I keep the subject constantly before me and wait until the first dawnings open little by little into the full light.' According to the famous story, the 'first dawnings' of his theory of gravity came to Newton when he saw an apple drop from a tree. This is often dismissed as sheer **legend**. But according to Newton's early biographer Stukely: 'he told me... the notion of gravitation came into his mind… occasion'd by the fall of an apple, as he sat in **contemplative** mood.'

It is important to understand the full significance of what Newton understood at that moment. What did he know already, and what did his eventual theory of gravity explain?

The key to it all was Kepler - who had taken over 20 years of painstaking observation and endless calculation before arriving at Kepler's three Laws of Planetary Motion. These were published in 1609 and stated:

1. The planets travel in **ellipses** around the sun, and the sun is at one focus of these eliptical orbits.



2. A straight line joining the sun and a planet sweeps out equal areas in equal times; (in the diagram right: time taken for planet p to travel from a to b, is the same as from c to d, and the area x is equal to area y).

3. The square of the time taken for one complete orbit by a planet, is proportional to the cube of its average distance from the sun; (in the diagram: if planet p takes time T to complete an orbit, and r is the average radius of this orbit, then: $T^2 = r^3$).

Meanwhile back on earth, Galileo had confirmed by experiments, said to have been conducted from the Leaning Tower of Pisa, that a falling body accelerates at a uniform rate. He also derived a formula for the parabolic path of a projectile - such as the path of a stone thrown over a distance, or a ball fired from a cannon.

Newton's genius was to put Kepler's Laws and Galileo's findings together. The notion of gravity which came to him when the apple fell from the tree would eventually be seen as the same power which held the moon in orbit around the earth, and the planets in orbit around the sun. The laws which applied on earth also applied to heavenly bodies. This was a **stupendous** **intuition**. At one step, our understanding was no longer earth-bound, but extended throughout the universe. (Kepler's laws merely described what happened, Newton explained why.)

Newton was not to publish his ideas for over 20 years. There are several reasons for this. At first he only regarded gravity as applying on earth. Later, when he extended this to **extraterrestrial** bodies, he couldn't quite work out the mathematics of it. How did the earth's gravitational force actually work? Did it attract the moon from its center or from its surface, or from somewhere in between? Not until he had refined the techniques of his newly discovered calculus was he able to overcome such problems.

Yet these weren't the only reason for his silence. Some have called Newton a secretive character. But this is not strictly true. The fact is, Newton couldn't **abide** being **contradicted**, even in the most **trivial** matter. It was **liable** to make him burst into one of his uncontrollable rages. So rather than face the questioning of his fellow scientists, he preferred to keep his discoveries to himself

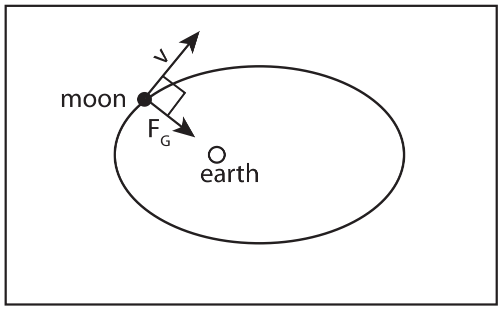
Needless to say, such psychology only accounts for Newton's personality. It may be likened to a map of the world. This outlines the **contours** and shapes, but in no way explains the magnificence and **profusion** of the reality. The sheer quality of Newton's mind remains utterly **inexplicable**.

During the 20 years before Newton published his findings on gravity, his initial insight became refined into a **comprehensive** system. It was this which finally appeared in his masterpiece the Principia. Here Newton went one step further than Kepler and Galileo, putting forward three laws of his own which **superseded** their findings.

Newton's first law of motion **posits** a theory of inertia, stating that a body

remains at rest or in uniform motion along a straight line unless it is acted upon by an outside force. Things moved through space because there was nothing to stop them after they had initially been set in motion. For the first time the movement of bodies through the heavens was explained - without **recourse** to divine juggling or locomotion by angels. (Though not until three centuries later did the Big Bang Theory explain how this initial motion had come into being.)

Newton's second law of motion states that the rate of change of momentum (mass x velocity) of a moving body is **proportional** to the force impressed upon it. In other words, the effect of a continuous force upon a stationary body or one in uniform motion is to make it accelerate. Galileo had discovered this when he dropped objects from the Leaning Tower of Pisa. The pull of gravity makes a body accelerate. The same happens when the moon orbits the earth.



The continuously acting force of gravity (F_G) **impels** the moon to accelerate towards the earth, but the moon's momentum (mass x velocity) impels it along the line of velocity (v). The resulting continuous balance of forces keeps it in orbit. To discover the force of gravity operating here, Newton had to calculate the moon's rate of change of momentum. As the moon's orbit is an **irregular** ellipse, this involved calculating the velocity of an object moving in a curve. It was in his earliest attempts to solve this problem that Newton employed his newly discovered **fluxions**, and in the process developed **differential calculus**.

Newton's third law of motion states that if one body exerts a force on another, the second will exert an equal and opposite reaction on the first. Newton's concept of force in these laws was to transform science. It united Descartes' recent mechanical view of the world with the ancient tradition of **Pythagoras**, who claimed that the world ultimately consisted of numbers. This combining of mechanics and mathematics not only explained how the world worked, but meant we could also calculate precisely what was happening in it.

By using these three fundamental laws, Newton was finally able to conclude how gravitational force acted between two bodies. He showed that this is directly proportional to the product of their two masses, and inversely proportional to the

square of the distance between their two centers. This was expressed in his celebrated formula (the E = mc2 of its day):

$$F_G = G\, m_1 m_2 \; / \; d^2$$

Where F_G is the force of gravitational attraction, m_1 and m_2 are the masses of the earth and the moon, d is the distance between their centers, and G is the gravitational constant. What had set him on the path to this formula was the possibility of the inverse square relation - and this may well have been the original realization provoked by the falling apple. Newton didn't understand the entire notion of gravity in a flash; but this was what set him on the long and complex mathematical journey which ended in his law of gravitation. Even so, it was to be a century before the **eccentric** English **physicist** Cavendish managed to determine the value of G, the gravitational constant. However, this incompleteness didn't stop Newton from making sweeping claims for his new law. He asserted that the Law of Gravitation applied throughout the universe. This was of course a hypothesis: Newton's calculations were based entirely on observations of the moon and the discovered planets. But Newton would **brook** no objection claiming: '*Hypotheses non fingo*'- (I do not make up hypotheses.)

It is difficult for us to understand the sheer flimsiness of Newton's claim with regard to his gravity law - which he insisted upon calling the *Universal* Law of Gravity. One of the greatest human insights of all time was in fact little more than a hunch - a guess of transcendent genius.

There may have been scanty scientific evidence for Newton's claim of universality, but it certainly accounted for many observed facts and **eccentricities** of planetary movement. Most interestingly, it explained Kepler's laws and also accounted for irregularities in the orbits of the moon and planets (these occurred when they were affected by the gravitational pull of other passing planets as well as that of the sun).

Newton's bold guess changed everything. From now on scientists believed that anything which happened in the universe could be explained in terms of mathematics. This has remained one of the central beliefs of modern science. Indeed, it is the cornerstone of the continuing quest for a Theory of Everything which will explain the fundamental workings of the universe and everything in it.

Name: ______________________________

Period: __________ Table: ___________

General Physics
Newton & Gravity
Apple and Gravity
Vocabulary

calculus

embryo

transcendent

epoch

legend

contemplative

ellipses

stupendous

intuition

extraterrestrial

abide

contradicted

trivial

liable

contours

profusion

inexplicable

comprehensive

superseded

posits

recourse

proportional

impels

irregular

fluxions

differential calculus

Pythagoras

eccentric

physicist

brook

eccentricities